# CORRELATING WAVE TANK DISPERSANT EFFECTIVENESS TESTS WITH AT-SEA TRIALS

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**ABSTRACT**

*Two important questions facing oil spill responders, planners, and researchers are:*

1. *What is the limiting viscosity of oil for dispersant use; and*
2. *How well do results from dispersant effectiveness tests performed in laboratory apparatus and experimental wave tanks reflect dispersant performance at sea?*

*In order to begin addressing these questions, a series of at-sea dispersant effectiveness trials were completed in the UK in the summer of 2003 to estimate the viscosity of spilled fuel oils that limits dispersant effectiveness under conditions of moderate sea states (Beaufort Sea states 2 to 4) (Lewis 2004). Two well-characterized marine fuel oils (IFO 180 and IFO 380) with viscosities of 2000 and 7000 cP were spilled, sprayed with dispersants, and dispersant effectiveness was assessed. Several types of dispersants and a range of dispersant dosages were tested. These tests are currently being repeated using a variety of laboratory and meso-scale dispersant effectiveness apparatus to determine how well the results of these various test methods correlate with dispersant performance at sea.*

*Dispersant effectiveness tests in the SL Ross wave tank, using the identical oils and dispersants from the UK offshore trial, were the focus of this study. The goal of the work was to determine if the dispersant effectiveness test results from this tank are similar to results measured in the offshore.*

*The tank testing indicated that the IFO 180 oil (viscosity of 2000 cP at the test temperature of 16 °C) is readily dispersible with Corexit 9500 and Superdispersant 25 when applied at dispersant-to-oil ratios (DORs) exceeding 1:75 for Corexit 9500 and 1:50 for Superdispesant 25. The IFO 380 fuel oil (viscosity of 7000 cP at the test temperature of 16°C) was 53% dispersed when treated with Corexit 9500 at a DOR of 1:30. The IFO 380 oil can be dispersed, but larger quantities of dispersant must be applied to achieve significant results.*

*The tank test dispersant effectiveness results measured for the Corexit 9500 dispersant were similar to the UK field test trends for the IFO 180 oil and were somewhat higher than the field results for the IFO 380 oil. The tank test results for Superdispersant 25 were slightly higher than the field trial trends for the IFO 180 oil and slightly lower for the IFO 380 oil. The limited data available for the Agma DR379 dispersant suggests that the tank test results were similar to the offshore trial results for the IFO 180 oil and lower for the IFO 380 oil.*

*In general, the SL Ross tank test results matched the trends in the offshore results reasonably well. Variations in sea states and DORs during the sea trials, insufficient data points for direct comparison and the lack of resolution in the 4-point visual assessment system do not permit a more definitive comparison of the results of the test programs.*

## INTRODUCTION

A series of at-sea dispersant effectiveness trials were completed in the UK in the summer of 2003 to estimate the viscosity of spilled fuel oils that limits dispersant effectiveness under conditions of moderate sea states (Beaufort Sea states 2 to 4) (Lewis 2004). Subsequent to this study a number of additional bench and tank scale dispersant studies have been completed to compare the dispersant effectiveness results from laboratory or tank tests to those measured in the UK offshore trial. A common objective of all of these studies has been to determine the viscosity of oil that limits the effectiveness of oil spill dispersants.

The objective of the work reported in this paper was to complete SL Ross wave tank dispersant effectiveness tests on identical oils and under similar conditions to the UK trials, to correlate the tank test results with those from the offshore program.

For many types of dispersant tests the SL Ross tank offers several advantages over smaller lab-scale tests without the expense involved with field testing or larger meso-scale tank testing such as that completed at Ohmsett. Previous testing in this facility has provided results that were very similar to the large-scale dispersant effectiveness tests that have been completed at the Ohmsett facility. The goal of this study was to determine if the dispersant effectiveness test results from this tank are similar to those achieved in the offshore.

## TEST PROTOCOL AND APPROACH

In the UK at-sea dispersant trials small amounts of fuel oil were spilled, immediately sprayed with dispersants, and the ensuing dispersant effectiveness visually assessed by a group of expert observers using a four-point scale developed for this purpose (Lewis 2004). The four-point scale used in this study is presented in Table 1.

The types of fuel oils, dispersants and dispersant-to-oil ratios (DORs) proposed and used in the UK trials are summarized in Table 2. The table cells with the '**X**' represent tests actually completed in the UK trials.

**Table 1. Proposed Standard Method for Visually assessing and Reporting Dispersant Effectiveness in UK At-Sea Trials 2003**

| Rank | Standard Phrase | Description |
|---|---|---|
| 1 | No obvious dispersion | Dispersant being washed off the black oil as white, watery solution leaving oil on surface. Quantity of oil on sea surface not altered by dispersant |
| 2 | Slow or partial dispersion | Some surface activity (oil appearance altered). Spreading out of oil. Larger droplets of oil (1 mm in diameter or greater) seen rapidly rising back to sea surface, but overall quantity appears to be similar to that before dispersant spraying |
| 3 | Moderately rapid dispersion | Quantity of oil visibly less than before spraying. Oil in some areas being dispersed to leave only sheen on sea surface, but in other areas still some oil present. |
| 4 | Very rapid and total dispersion | Oil rapidly disappearing from surface. Light brown plume of dispersed oil visible in water under the oil and drifting away from it |

**Table 2. Test Matrix from UK At-Sea Trials and Wave Tank Tests**

| Dispersant Conditions | | Types of Oils | |
|---|---|---|---|
| **Dispersant Type** | **DOR[1]** | **IFO-180** | **IFO-380** |
| **Control** | no dispersants | X | X |
| **Corexit 9500** | 1:25 | X | X |
| | 1:50 | X | X |
| | 1:100 | X | |
| **Superdispersant 25** | 1:25 | X | X |
| | 1:50 | X | X |
| | 1:100 | | |
| **Agma DR 379** | 1:25 | X | X |
| | 1:50 | | |
| | 1:100 | | |

[1] DOR = target or proposed dispersant-to-oil ratio

A similar protocol was used in the wave tank tests, with the exception that the assessment of dispersant effectiveness was performed in two ways: a) by visual means using the four point scale; and b) by collecting and measuring the amount of oil remaining on the surface at the end of each run. The small wave tank tests were completed under similar conditions to the at-sea tests, including using the identical oils and dispersants, similar dispersant dosages, water salinities, and temperatures. The major difference between the tests was the mixing energy. The at-sea tests were performed in waves ranging from 1 to 2 feet in height, with occasional cresting waves. The wave-tank tests were performed in waves ranging from 6 to 10 inches in height with occasional cresting waves. The results of the wave tank tests have been compared to the at-sea tests in order to determine: a) whether the wave tank can successfully distinguish effects of oil type, dispersant type and dosage on dispersibility results, as was the case in the at sea trials; and b) whether effectiveness levels observed in the apparatus were significantly higher or lower than in the at sea tests.

The test apparatus and test methods used in the wave tank dispersant effectiveness tests are described in detail elsewhere (SL Ross 2002). A picture of the test tank is shown in Figure 1. The tank is 1m wide by 1m deep by 11m long. Dispersant is applied using an overhead spray bar. Waves are generated using a wave paddle at one end of the tank and a wave-dissipating beach at the other. Oil is held in the centre of the test tank using an air-curtain bubble barrier system.

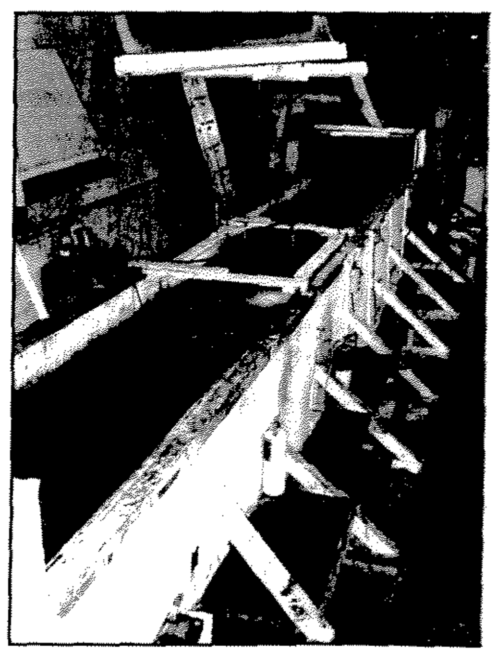

FIGURE 1. SL ROSS WAVE TANK

The properties of the oils tested are provided in Table 3.

## TEST RESULTS

### TANK TEST RESULTS

The dispersant effectiveness results from the testing are provided in Table 4. When a dispersant was completely effective at a low dosage, tests were not completed for higher dispersant application rates. Conversely, when a dispersant was ineffective at a high application rate a lower dose was not tested.

Figures 2 and 3 show the relationships between dispersant effectiveness, DOR, and dispersant type for the IFO 180 and IFO 380 oils, respectively. The results show that Corexit 9500 was more effective than the Superdispersant 25 at all DORs, and both were more effective than Agma DR379 at a DOR of 1:25. The IFO 180 fuel oil was highly dispersible in this test using the Corexit 9500 and Superdispersant 25 dispersants in DORs above 1:50.

The IFO 380 fuel oil was less dispersible than IFO 180 by all dispersants in this tank testing. Corext 9500 was the most effective dispersant, followed by the Superdispersant 25 and the Agma DR379. Corexit 9500 achieved a 53% dispersion of the IFO 380 at a dose rate of 1:30.

In general, the tank tests indicate that the IFO 180 oil (viscosity of 2000 cP at test temperature of 16 °C) is readily dispersible with Corexit 9500 and Superdispersant 25 when applied at DORs exceeding 1:75 and 1:50, respectively. The IFO 380 fuel oil (viscosity of 7000 cP at test temperature of 16 °C) was 53% dispersed when treated with Corexit 9500 at a DOR of 1:30. This viscous oil can be dispersed, but larger quantities of dispersant must be applied to achieve significant results.

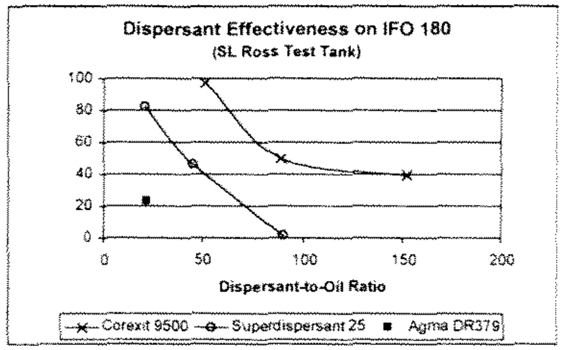


FIGURE 2. DISPERSANT EFFECTIVENESS ON IFO 180 IN TANK TESTS

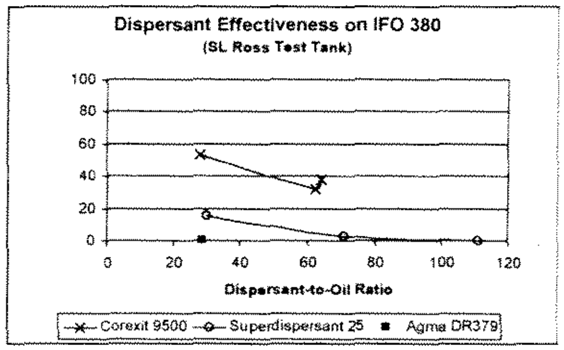


FIGURE 3. DISPERSANT EFFECTIVENESS ON IFO 380 IN TANK TESTS

**Table 3. Physical Properties of Fuel Oils**

| Oil Type | Density (kg/m³) @ 20°C | Viscosity Pa.s (cP) | | | |
|---|---|---|---|---|---|
| | | @ 16°C | | @ 50°C | |
| | | @ 10 s⁻¹ | @ 100 s⁻¹ | @ 10 s⁻¹ | @ 100 s⁻¹ |
| **IFO 380** | 0.983 | 7100 | na | 314 | 324 |
| **IFO 180** | 0.970 | 2075 | 1925 | 134 | 146 |

na—not available

**Table 4. Wave Tank Test Results: Dispersant Effectiveness (%)**

| | IFO-180 | | | IFO-380 | | |
|---|---|---|---|---|---|---|
| | | Effectiveness | | | Effectiveness | |
| Dispersant Type | DOR[1] | (%) | Visual Ranking | DOR[1] | (%) | Visual Ranking |
| **Control** | no dispersants | 0 | 1 | No dispersant | 0 | 1 |
| **Corexit 9500** | 1:50 | 97 | 4 | 1:30 | 53 | 3 |
| | 1:90 | 50 | 3 | 1:60 | 32 | 3 |
| | 1:150 | 39 | 3 | 1:60 | 38 | 3 |
| **Superdispersant 25** | 1:20 | 82 | 3 | 1:30 | 15 | 1 |
| | 1:50 | 46 | 3 | 1:70 | 3 | 1 |
| | 1:90 | 2 | 2 | 1:110 | 0 | 1 |
| **Agma DR 379** | 1:20 | 23 | 2 | 1:30 | 0 | 1 |

[1] DOR = actual dispersant-to-oil ratio

The visual rankings of dispersant effectiveness follow the same general trend as the measured effectiveness, as seen in Figure 4.

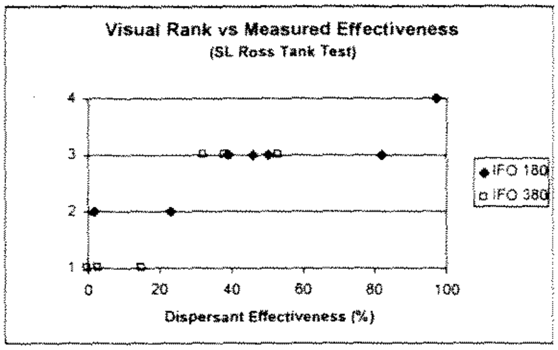


FIGURE 4. VISUAL RANKING VS MEASURED EFFECTIVENESS FOR TANK TEST RESULTS

The #3 ranking bracketed the largest range of actual effectiveness values. This is not surprising in these tank tests as the entire oil slick and dispersed oil cloud can be seen during the duration of the test. Any test with a significant amount of oil left on the surface at the end and a visible cloud of oil present in the water at the beginning automatically relegates the effectiveness to a #3 visual rank. In a field situation small amounts of oil would likely go undetected both on the surface and in the water and could result in #4 or # 2 ranking being assigned instead of a #3 ranking. Any dispersed oil generated during a test is also very visible; thus, a #1 ranking was only given for the IFO 380 oil where absolutely no dispersion was observed. Again, in a field situation where visibility is not as good, a #1 ranking would likely be more common. The high degree of visibility in the small tank test actually permits the observer to make a semi-quantitative estimate of the dispersion effectiveness based on the approximate change in surface area of the slick over the duration of the test. Such estimates were not recorded, but mental estimates were made that often closely matched the calculated effectiveness.

**Comparison of Tank Test Results with UK Field Trial Results**

A comparison of the measured effectiveness values from the test tank results to the visual estimates made by the expert observers in the UK offshore trials follows. The UK trial results have been extracted from Lewis, 2004. Table 5 shows the UK visual effectiveness rankings for similar DORs tested in the SL Ross wave tank. The values shown are averages from the responses from a number of observers and show the upper and lower range as ranked by the observers. Lewis's analysis of the observer's responses indicated that " There was little variation in the visual observations recorded by the individual expert observers; each observer seemed to be seeing the same effects, although there were some slight discrepancies. The observations were also consistent in general trends" (Lewis 2004).

The tank data and the UK field results in Table 5 are compared in Figures 5, 6, 7 and 8. In Figures 5 and 6 the visual rankings from the two studies are compared. In the second set (Figures 7and 8) the visual rankings from the UK field trial are compared to the numerical effectiveness values recorded in the tank tests. The "U" and "L" designations used in these figures refer to the upper and lower effectiveness rankings recorded in the UK field program and reported in Table 5. Generally, the higher effectiveness rankings recorded in the UK trials were associated with higher wind speeds (11 to 14 knots) and the lower effectiveness rankings with lower wind speeds (7 to 10 knots).

The following comments can be made regarding the visual ranking comparisons shown in Figures 5 and 6. The tank test visual rankings for the Corexit 9500 and Agma DR379 tests on IFO 180 (Figure 5) match the upper-effectiveness rankings from the UK trials relatively well, but are higher than the lower-effectiveness rankings from the offshore tests. The tank test visual rankings for the Superdispersant 25 tests on IFO 180 were higher than all of the observations made for this dispersant during the offshore trials. In the IFO 380 tests (Figure 6) one of the tank test results for Corexit 9500 matches the upper-effectiveness value reported in an offshore test. In the remainder of the Corexit 9500 tests on IFO 380 the tank results show a higher effectiveness than that recorded in the field. The reverse trend is seen for the other two dispersants. The tank results indicate a lower effectiveness than that observed

**Table 5. Wave Tank Dispersant Effectiveness (%) & UK Rankings**

| Dispersant Type | IFO-180 | | | | IFO-380 | | | |
|---|---|---|---|---|---|---|---|---|
| | DOR[1] | Effectiveness | | | DOR[1] | Effectiveness | | |
| | | SL Ross Tank | | At-Sea Visual Ranking | | SL Ross Tank | | At-Sea Visual Ranking |
| | | % | Visual | | | % | Visual | |
| **Control** | 0:1 | 0 | 1 | — | 0:1 | 0 | 1 | — |
| **Corexit 9500** | 1:50 | 97 | 4 | 3 to 4 | 1:30 | 53 | 3 | 1 to 3 |
| | 1:90 | 50 | 3 | 2.3 to 3.2 | 1:60 | 32 | 3 | 1.7 |
| | 1:150 | 39 | 3 | 1.8 to 2.3 | 1:60 | 38 | | |
| **Superdispersant 25** | 1:20 | 82 | 3 | 2 | 1:30 | 15 | 1 | 2 to 2.7 |
| | 1:45 | 46 | 3 | 1.7 to 2 | 1:70 | 3 | 1 | 1.4 to 1.6 |
| | 1:90 | 1.8 | 2 | 1 | 1:110 | 0 | 1 | |
| **Agma DR 379** | 1:20 | 23 | 2 | 1.4 to 2.5 | 1:30 | 0 | 1 | 1.2 to 1.7 |

[1] DOR = actual dispersant-to-oil ratio in Tank Tests, 0:1 control tests[1] DOR = actual dispersant-to-oil ratio

in the offshore tests, although the differences are not that significant with the exception of one of the upper-effectiveness rankings for a Superdispersant 25 test.

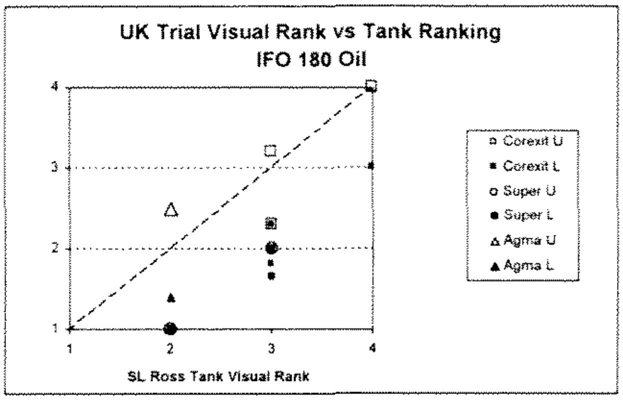


FIGURE 5. COMPARISON OF UK FIELD TRIAL RESULTS WITH TANK VISUAL RESULTS: IFO 180

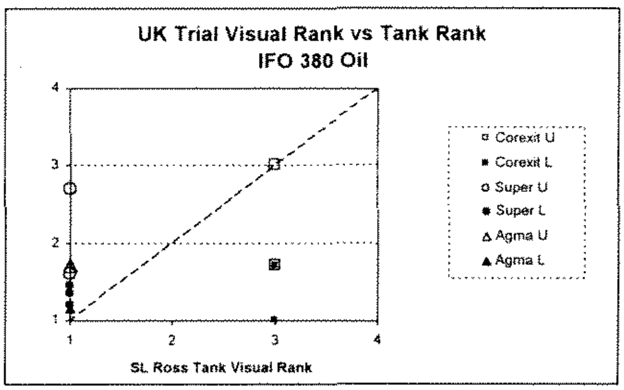


FIGURE 6. COMPARISON OF UK FIELD TRIAL RESULTS WITH TANK VISUAL RESULTS: IFO 380

The numerical effectiveness values recorded in the tank tests have been plotted against the visual rankings from the offshore trial. These results are shown in Figures 7 and 8 for the IFO 180 and IFO 380 oils, respectively. The trend lines for the upper and lower effectiveness comparisons for Corexit 9500 on the IFO 180 oil bracket the graph bisector indicating that there is a good agreement between the tank and offshore trial results for Corexit 9500 (Figure 7). The upper effectiveness values for Corexit 9500 correspond to offshore tests completed in 12 knots winds and the lower values for tests completed in 7 to 8 knot winds. This would suggest that the SL Ross test tank might be producing a mixing environment between these wind speeds. The Superdispersant 25 tests generated lower effectiveness values in both the field and tank tests when compared to the Corexit 9500 results at similar DORs and wind speeds. The Superdispersant 25 offshore tests on IFO 180 were completed in only low wind speed conditions (8 or 9 knots). The correlation of the tank test and offshore results for Superdispersant 25 in Figure 7 is similar to the lower effectiveness comparison for Corexit 9500 as might be expected since both results were recorded during the lower wind speed conditions. The tank test results for Superdispersant 25 at the highest DOR were somewhat higher than might have been expected based on the offshore observations. Agma DR379 offshore results are available only for one DOR (1:25) and wind speed condition (10 knots). The upper and lower effectiveness limits recorded in the offshore bracket the tanks results for the limited data available for the Agma product.

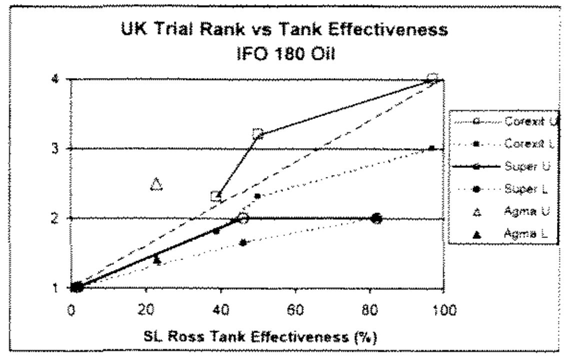


FIGURE 7. COMPARISON OF UK FIELD TRIAL WITH TANK NUMERICAL RESULTS: IFO 180

The IFO 380 tank test numerical effectiveness and field trial ranking comparisons are shown in Figure 8. Results are available only for two DORs (1:25 and 1:50) for Corexit 9500 and Superdispersant 25 and one DOR (1:25) for Agma DR379. The wide range of effectiveness values recorded for the offshore tests with Corexit 9500 at the higher DOR (1:25) is likely because one of the three high DOR offshore tests was completed in high winds (14 knots), while the other two were run in 8 to 8.5 knot winds and resulted in lower visual effectiveness ratings. The single, lower DOR (1:50) Corexit 9500 test was completed in 8 knot winds but yielded slightly higher visual effectiveness ratings than the higher DOR Corexit 9500 runs completed in similar wind conditions (8 knots) and thus the poor data correlation. The tank test results for Corexit 9500 show a reasonable correlation to the high wind offshore trial results for this dispersant. Superdispersant 25 tests at the high DOR (1:25) were also completed during both low (7.5 knots) and high (12 and 13 knots) wind conditions. The tank results for Superdispersant 25 were lower than would be expected based on the offshore observations. The tank test results for the single Agma DR379 test more closely match the lower of the offshore effectiveness ratings.

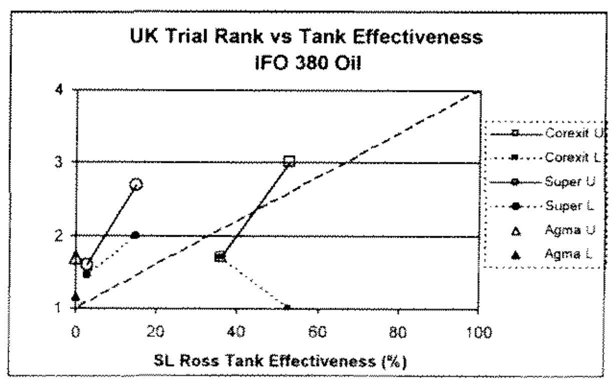


FIGURE 8. COMPARISON OF UK FIELD TRIAL WITH TANK NUMERICAL RESULTS: IFO 380 OIL

In general, the SL Ross tank test results matched the trends in the offshore results reasonably well. The tank test results appear to fall between the high wind speed and low wind speed results for many of the conditions tested. Variations in sea states and DORs during the sea trials, insufficient data points from the field program for direct comparison to tank test results, and the lack of resolution in the 4-point visual assessment system do not permit a more definitive comparison of the results of the two test programs.

## REFERENCES

Lewis, A. 2004. Determination of the Limiting Oil Viscosity for Chemical Dispersion at Sea, Final report for the DEFRA, ITOPF, MCA and OSRL. MCA Project MSA 10/9/180

SL Ross Environmental Research Ltd. 2002. Large-Tank Tests to Determine the Effectiveness of Corexit 9500 Dispersant when Applied to Hibernia Crude Oil on Cvold Water. Proceedings of the Twenty-Second Arctic and Marine Oilspill Program (AMOP), 2002